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SIZE INHERITANCE AND GROWTH IN A MOUSE SPECIES CROSS (MUS MUSCULUS × MUS BACTRIANUS)

IV. GROWTH¹

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ELEVEN FIGURES

Growth in plants and animals, a complicated process characterized by an increase through the gradual assimilation of new matter into the living organism, is a comprehensive term very difficult to define. In our investigation, however, growth merely denotes a general postnatal size increase indicated by the increase in weight.

In an effort to place the observed phenomena of growth on a mathematical basis, Brody ('26), Robertson ('23), and Crozier ('26), each with minor variations, have borrowed from chemistry the idea of autocatalytic monomolecular reactions. Brody ('26) states his idea that—

.... growth is a complex physico-chemical process but that the velocity of growth during given phases of growth is limited or governed by one chemical reaction—a master reaction as Robertson terms the limiting reaction—and that the time relations of each phase of the growth process may therefore be represented by the expression representing the time relations of the single limiting reaction.

With this idea, he develops the general formula—

$$W = A - \frac{V_0}{K} e^{-kt} \quad (W = \text{weight, } A = \text{mature weight}).$$

Snell ('29) considers that the theory that growth rate is controlled by an autocatalytic process is inherently defective.

¹One of a series from a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Zoölogy of the University of Michigan.

He recalls that an organism is not a closed system—since it constantly takes in and gives off—so special postulates are required. He further states:

An even more fundamental objection, one that unfortunately renders invalid the simple theories of growth proposed by Robertson and by Crozier, is that the equations they use do not apply to growing organisms because of the effect of increasing size on the concentration of the reagents involved in growth. The equations hold true only on the condition that the volume occupied by the reacting substances remains constant, and since a growing organism is constantly increasing in volume, this condition of course is not met. . . . It is on the *concentration* and not the amount of the reagents that the velocity of a reaction depends.

This, he thinks, demonstrates the invalidity of hypotheses according to which growth rate is controlled by a master autocatalyzed monomolecular reaction.

Regardless of the exact explanation, however, growth rates of animals exhibit certain definite characteristics. The period of growth in weight or volume, as Brody ('27) has pointed out, may be divided into two distinct phases: 1) a *self-accelerating* phase during which the velocity of growth increases with the size increase of the organism; and 2) a *self-inhibiting* phase, during which the velocity decreases with the increase in size of the organism. Each of these phases may consist of several cycles, the number, in general, being characteristic for a particular form.

These characteristics have been worked out for several forms. Among the published reports are those of Brody ('21) and Latimer ('24) for the domestic fowl, Brody and Ragsdale ('21) for the dairy cow, King ('15, '23) and King and Donaldson ('29) for rats, and Davenport ('26) and Brody ('28) for man.

The normal growth of the white mouse has been analyzed by Robertson ('16, '26). In each sex there are three extra-uterine growth cycles, the whole growth process consisting of three autocatalytic processes and one 'linear process' of weight accretion. The first cycle attains its maximum velocity at some time shortly prior to seven days after birth; the

second, at twenty-one to twenty-three days; and the third, at about six weeks. Parkes ('26) studied the growth of mice during the first twenty-one days of life and noted active phases in the first and third weeks with a comparatively stagnant period in between. Gates ('25), likewise studying mice during their first three weeks, found that the rate of growth showed a gradual increase at first, followed by a period of slight gain reaching its minimum at the seventeenth day, and again a final increase as the young became independent of nursing.

Davenport ('26) observes that the total growth in weight is the sum of the weights of its constituent organs. In some cases these keep pace with the growth of the body as a whole and great acceleration in total weight is due to rapid increase in weight of the organs. In other instances, some organs may undergo a change (such as the thymus gland), which is not in keeping with the body as a whole. Schmalhausen ('29) elaborates on this and explains that the general parabolic character of the growth curve of the organism as a whole is the result of the summation of the parabolic growth curves of the single tissues and organs. Since these are laid down at different times and possess different innate growth intensities, growth of the organism as a whole is not a homogeneous process. The division of the growth processes into single periods, which correspond to several natural life periods (embryonic period, larval period, etc.), is so sharply delineated that an exact mathematical description of the whole process, without artificial obliteration of the limits, is impossible.

MacDowell ('28), on the basis of his investigations on the growth curve of the suckling mouse, advances another objection to current theories regarding the innate cyclic nature of growth. In mammals the most uniform conditions prevail during prenatal life and a study based upon nearly 1000 embryos gives a growth curve in the form of a continuous parabola of the $W = Kt^n$ (t being counted from the appearance of the anlagen of the embryo). The most uniform con-

ditions in postnatal life are found during the nursing period. Ordinarily, however, curves of this period are not parabolas, since they show a decline during the second week (the so-called infantile growth cycle). The quantity of the mother's milk is the limiting factor under normal conditions, and when this factor is removed the growth which produces a 14-gram mouse in fourteen days has the nature of a continuous parabola. Thus, at least one of the cycles of mammalian growth, he believes, cannot be attributed to innate causes, but to the amount of food available.

Regardless of whether the forces underlying growth can be explained as autocatalytic monomolecular reactions or whether the apparently innate cycles are in reality artifacts, even a gross examination of growth curves based on averages discloses features characteristic of each species or race. Such curves present graphically the rate at which development 'normally' proceeds under natural conditions, although, as MacDowell has shown, this rate can be changed by giving a suckling mouse an immoderate and unusual supply of milk during the period when a relative diminution ordinarily takes place. The curves in this report are intended only to portray this 'normal' rate and to show the manner in which the very different final sizes of the animals in our investigation were attained.

MATERIAL AND METHODS

The material for this study of growth consisted of pure stocks of *Mus bactrianus* (in this paper, B), a small, light-colored, white-bellied mouse possessing the genes affecting coat color for intense, black, and agouti, and the 'Little' inbred strain of dilute brown non-agouti *Mus musculus* (in this paper, M), both types of reciprocal F_1 hybrids ($M \text{♀} \times B \text{♂}$ and $B \text{♀} \times M \text{♂}$), and two types of back-cross matings ($M \text{♀} \times F_1 \text{♂}$ and $F_1 \text{♀} \times M \text{♂}$). Since the parental forms differs in three allelomorphic color characters, the back-cross generation consisted of eight color classes in approximately equal numbers.

Our B mice were descendants of animals taken near Peiping, China, and brought to the United States in 1926 by Dr. Sheo Nan Cheer. Specimens of our stock have been identified by Dr. G. M. Allen as intermediate between the Gobi Desert form, *Mus bactrianus gansuensis* Satunin, and the subspecies inhabiting western China, *Mus bactrianus tantillus* Allen (1927)—on the whole, probably nearer the former.

All mice in the experiment were weighed individually. At first a set of balance scales was employed, but this was soon superseded by a set of specially designed scales manufactured by the Toledo Scale Co. Individuals weighing less than 10 grams were weighed to the nearest 0.01 gram; those above that weight, to the nearest 0.1 gram. The newborn mice were suckled by their own mothers and those cases in which the young were transferred to foster mothers of another species were not included in the tabulations. This policy excluded the abnormal early weights attained by some of the B young which were nursed by M foster mothers. King ('23) found that young Norway rats nursed by albino females still retained their characteristic growth curves, so our precautionary policy may have been unnecessary.

With the exception of one litter which was separated from the mother on the thirtieth day, all young were weaned and ear-marked on the thirty-first day after birth, although they had doubtless been self-sustaining for ten days or more. Weighings were taken the first day and every second day thereafter until the thirty-first day, then at ten-day intervals until the 181st day. No individuals dying before weaning were included in the computations. In arriving at the averages of animals after the age of thirty-one days no weights were included which were taken less than ten days before an animal's death. Since lingering diseases among mice are rare, this probably insured the inclusion of healthy animals only.

Since, as has been pointed out, the bearing of young may influence the final size of a female, the weights of animals,

which became parous prior to the age of 181 days, were, after the age of thirty-one days, tabulated separately from those which did not. The charts present the data for nulliparous females only.

DISCUSSION OF DATA

Chart 1 shows the growth curves for M and B males and for males of the two types of F_1 hybrids. The M averages for the thirty-one age groups are based on from 48 animals

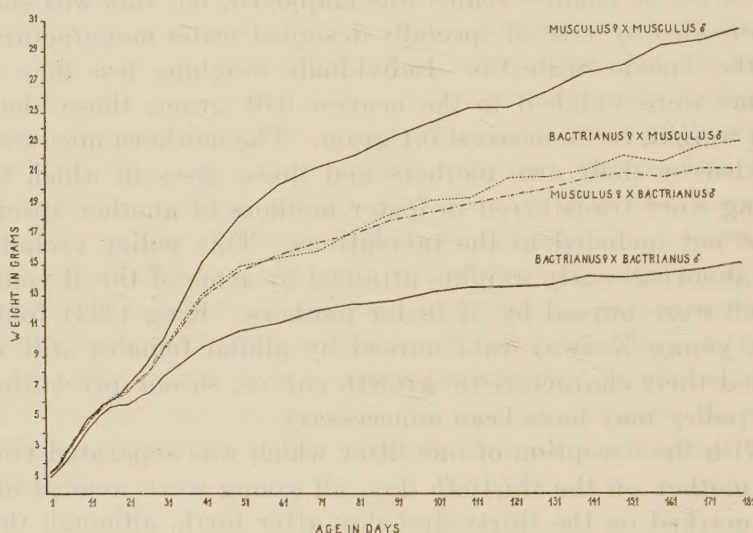


Chart 1 Growth curves. Males.

in the earlier periods to 25 in a later; the B, from 46 to 17. The F_1 males from M mothers have from 56 to 35 in each age group, while the reciprocal males have from 20 to 13.

In chart 2 are presented growth curves for the females (nulliparous) for the same matings. Here the numbers in the age groups vary as follows: M, 49 to 23; B, 59 to 10; F_1 's from M mothers, 66 to 18; F_1 's from B mothers, 22 to 17.

M averages exceed those of B at all ages, both for males and females. The early weights of both types of hybrid mice are nearly identical with those of the larger parent. After

the first major inflection (the lessened increase incident to independent existence) at about the seventeenth to nineteenth day, the F_1 's begin to deviate sharply from M, although they remain closer to the larger species until the forty-first or fifty-first day. Thereafter, they are intermediate between the two parents, the males nearly equidistant, but the females nearer to B. The curves for the two types of F_1 matings lie very close together and show no important differences. Heterosis does not seem to have induced an early accelerated growth rate.

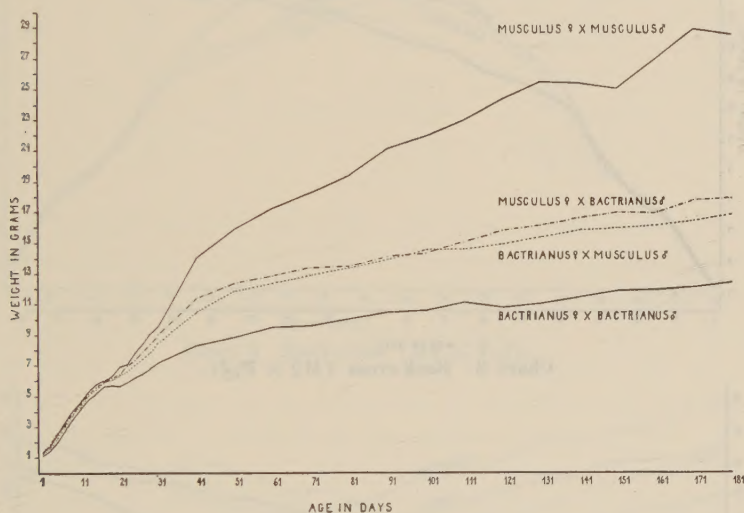


Chart 2 Growth curves. Females.

Growth curves for the back-cross mating ($M \text{♀} \times F_1 \text{♂}$) are presented in charts 3, 4, and 5. The curve for the agouti males (based on averages of from 51 to 32 animals) is almost identical with that for the non-agoutis (39 to 30 animals). The non-agouti females (38 to 30 animals), on the other hand, show a consistent tendency after the seventy-first day to be heavier than the agouti (41 to 28 animals), the greatest difference occurring in the most advanced age groups. When the blacks and browns are compared (chart 4), it is apparent that the browns are heavier than the blacks. This holds true

for both sexes. In females this difference is not in evidence until the seventy-first day, while in the males it is present after the thirty-first day. The number of brown males varied from 46 to 31; the number of black males, from 44 to 31. There were from 41 to 31 brown females and from 38 to 27

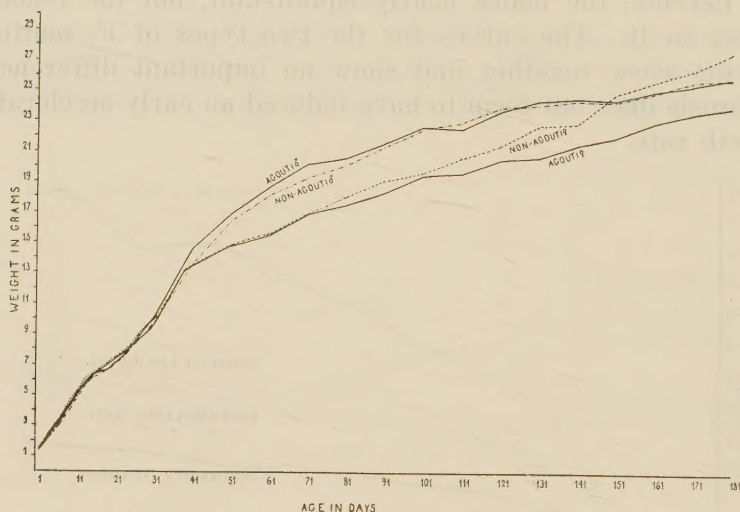


Chart 3 Back-cross ($M♀ \times F_{1♂}$).

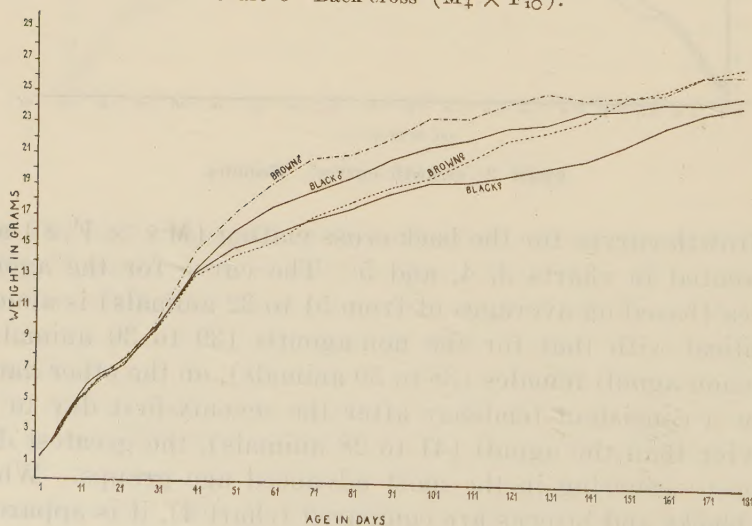


Chart 4 Back-cross ($M♀ \times F_{1♂}$).

black females in each age group. The differences between intense and dilute mice from this mating are slight. Here the numbers of animals were as follows: Males: intense, 42 to 31; dilute, 48 to 32; females: intense, 34 to 24; dilute, 45 to 35.

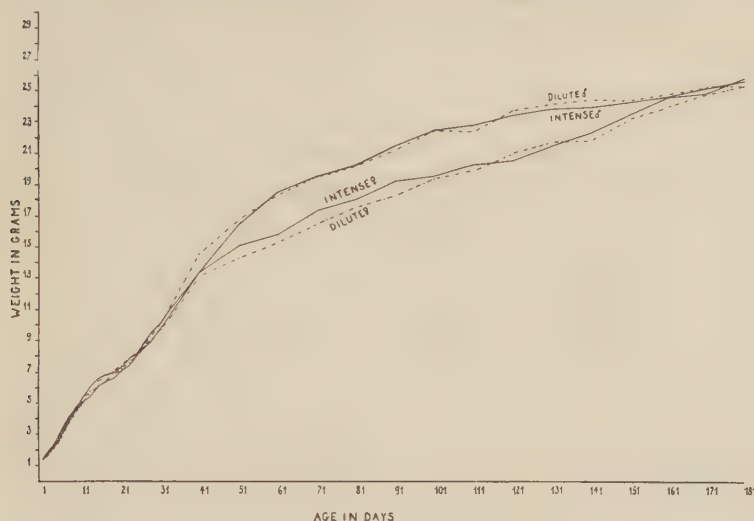


Chart 5 Back-cross ($M_{\text{♀}} \times F_{1\text{♂}}$).

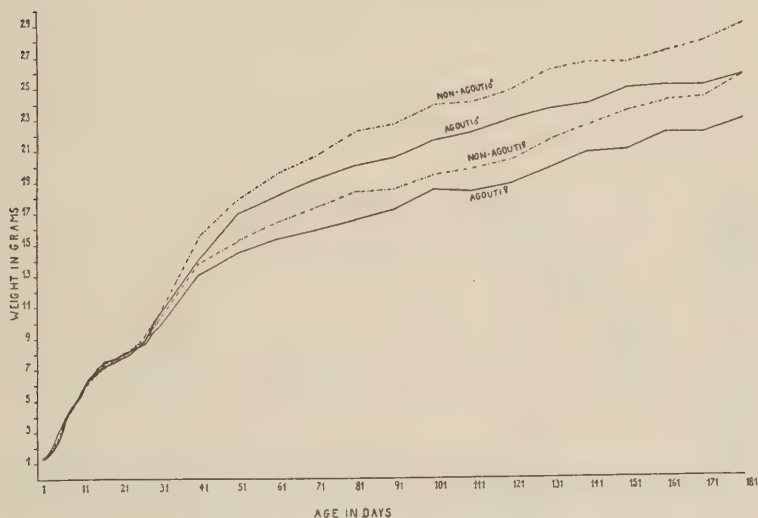


Chart 6 Back-cross ($F_{1\text{♀}} \times M_{\text{♂}}$).

Average weights for the reciprocal back-cross mating ($F_1 \text{♀} \times M \text{♂}$) are presented graphically in charts 6, 7, and 8. Chart 6 discloses that non-agouti mice of both sexes are consistently heavier than agouti. This condition holds even before weaning. Chart 7 reveals much the same situation for

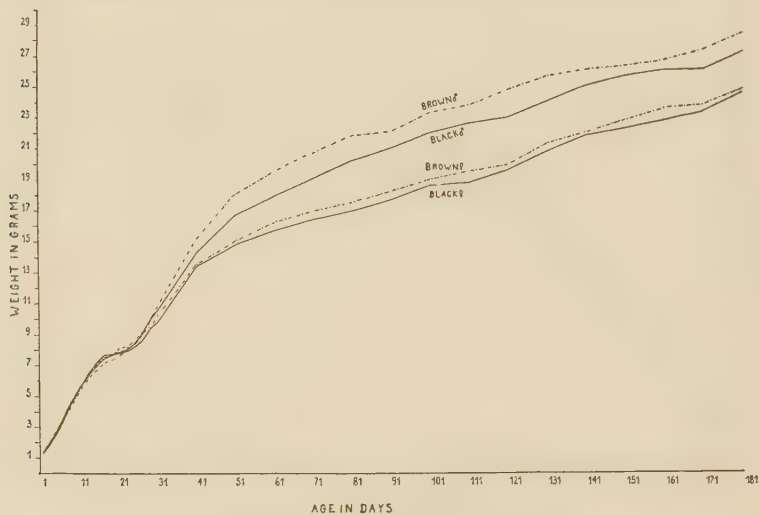


Chart 7 Back-cross ($F_1 \text{♀} \times M \text{♂}$).

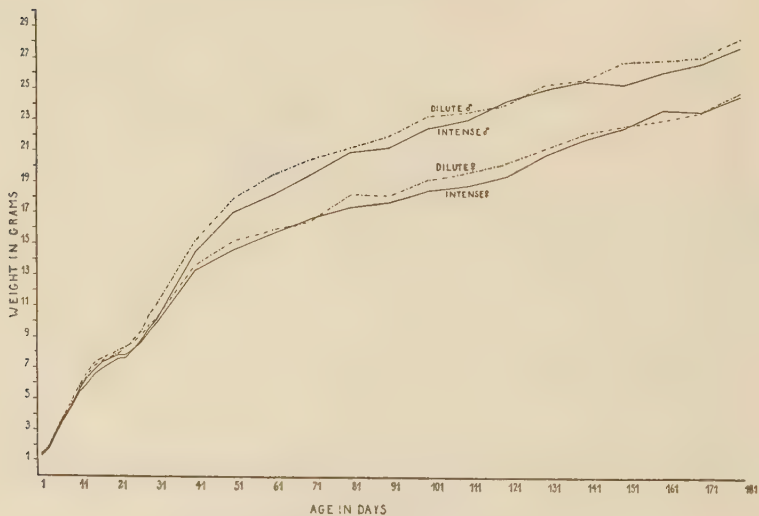


Chart 8 Back-cross ($F_1 \text{♀} \times M \text{♂}$).

browns and blacks. Here the differences are comparatively slight, but nevertheless consistent, the recessive browns being heavier. In comparing the intense and dilute animals the differences are slight and inconsistent, although there is a general tendency for the latter to exceed the former.

The number of mice in the different classes of this back-cross is given in table 1.

TABLE 1
Back-cross mating ($F_1\text{♀} \times M\text{♂}$)

<i>Phenotype</i>	<i>Number of males</i>	<i>Number of females</i>
A ^w	62 to 32	46 to 30
a	65 to 36	51 to 36
B	52 to 23	48 to 31
b	75 to 45	48 to 35
D	65 to 33	55 to 34
d	62 to 35	42 to 32

The consideration of both types of back-cross matings shows a general tendency for non-agoutis to be heavier than the agoutis and for browns to be heavier than blacks, while little difference is evident between dilute and intense animals. This may indicate that more genes—or genes of greater potency—affecting size are present on the chromosomes of the musculus parent possessing the genes a and b than on the chromosome with d. All back-cross growth curves, however, are essentially of the same general type as that of the parent species and the F_1 's.

The fact that animals possessing the recessive genes for non-agouti and brown tend to be heavier than those with the dominant allelomorphs is contrary to what might be expected were there no tendency for the large size and recessive qualitative characters of the M parent to remain associated in the back-cross animals. In general, recessive characters are more deleterious than dominant ones—as Collins ('21) and Wright ('22) have pointed out—so it is unlikely that the recessive characters in our mice are, per se, more conducive to growth than the dominants. Detlefsen and Roberts ('18), it will be recalled, found that mice of the wild gray type (intense black

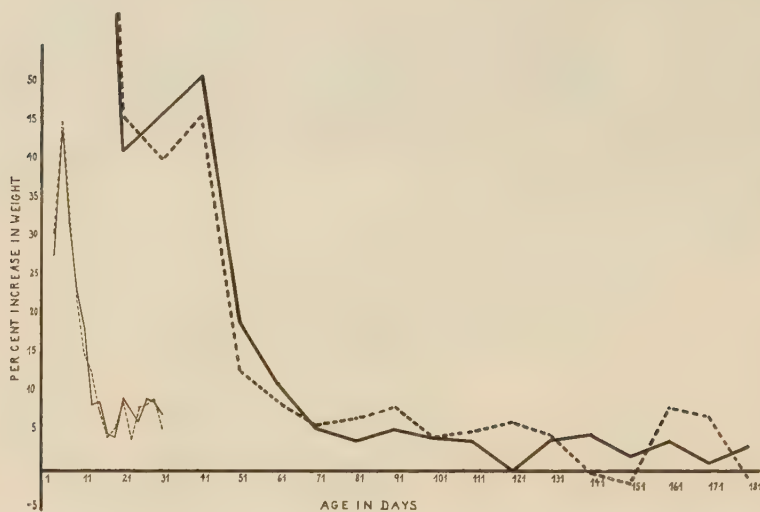


Chart 9 Relative increase in pure musculus. Solid lines, males. Broken lines, females. Heavy lines represent increases based on ten-day periods; light lines, two-day periods.

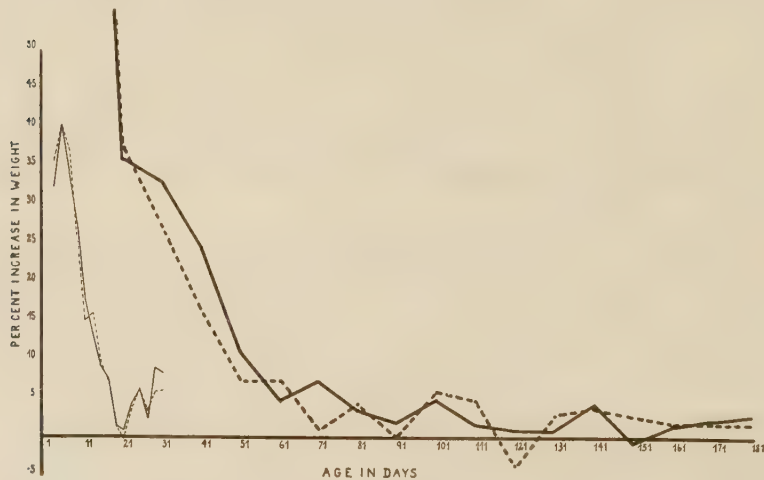


Chart 10 Relative increase in pure bactrianus. Solid lines, males. Broken lines, females. Heavy lines represent increases based on ten-day periods; light lines, two-day periods.

agouti) survived better in laboratory competition than their recessive litter mates, the aggregation of dominant factors apparently making for especially vigorous animals.

Although a survey of growth curves gives a good idea of the manner in which increase in weight progresses in the two species, charts of relative (percentage) increase present the data in a form more suitable for comparison. These data are given for pure musculus matings in chart 9, for pure bac-

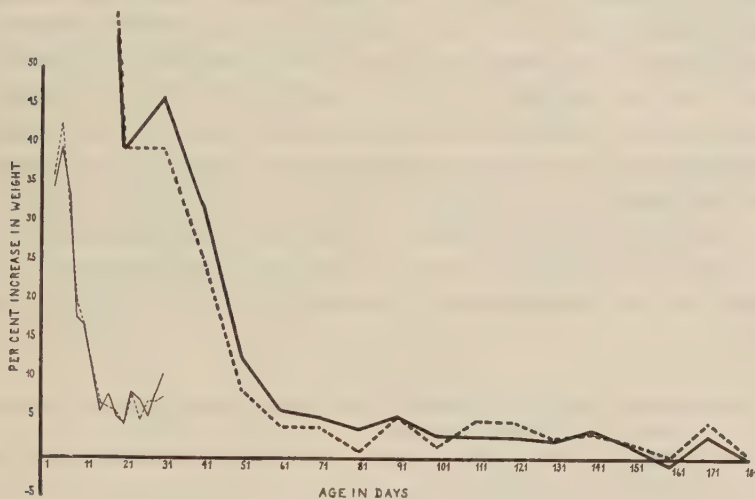


Chart 11 Relative increase in F_1 ($M\sigma \times B\phi$). Solid lines, males. Broken lines, females. Heavy lines represent increases based on ten-day periods; light lines, two-day periods.

trianus in chart 10, and for the F_1 animals ($M\phi \times B\sigma$) in chart 11. The two species and the hybrids agree in that the greatest percentage increase takes place between the third and the fifth day. From this point the relative increase drops rapidly until the low point concomitant with the change in food habits is reached. In musculus this seems to occur at approximately the seventeenth day, while in bactrianus and the F_1 hybrids this minimum is encountered between the nineteenth and the twenty-first day. Another period of active growth sets in and probably continues until after puberty,

when the increments in weight become slight and more or less irregular. There seem to be no marked sexual or specific differences in this respect, although males in general in all our mice are heavier at all ages than females.

SUMMARY

The general forms of the curves for growth in weight of the parent species, *Mus musculus* and *Mus bactrianus*, and of the hybrid generations (F_1 and back-cross) exhibit no marked differences. All are characterized by an initial period of rapid growth, followed by a relatively stagnant period incident to the change in food habits. Another period of increased rate takes place and continues until after puberty, when growth again occurs more slowly. Many of the animals are still showing slight gains in weight at the age of 181 days. The back-cross curves present indications that more factors—or factors of greater potency—affecting weight may be located on the chromosomes carrying a and b than on that with d.

LITERATURE CITED

- DE ABERLE, S. B. 1927 A study of the hereditary anemia of mice. *Am. Jour. Anat.*, vol. 40, pp. 219–247.
- ALLEN, G. M. 1927 Murid rodents from the Asiatic expeditions. *Am. Mus.-Novitates*, no. 270.
- BELLING, J. 1915 Inheritance of length of pod in certain crosses. *Jour. Agr. Res.*, vol. 5, pp. 405–420.
- BRODY, S. 1921 The rate of growth of the domestic fowl. *Jour. Gen. Physiol.*, vol. 3, pp. 765–770.
- 1926 Time relations of growth. I. Genetic growth constants of animals. *Jour. Gen. Physiol.*, vol. 8, pp. 233–251.
- 1927 Time relations of growth. III. Growth constants during the self-accelerating phase of growth. *Jour. Gen. Physiol.*, vol. 10, pp. 637–658.
- 1928 A comparison of growth curves of man and other animals. *Sci., N.S.*, vol. 67, pp. 43–46.
- BRODY, S., AND RAGSDALE, A. C. 1921 The rate of growth of the dairy cow. *Jour. Gen. Physiol.*, vol. 3, pp. 623–633.
- BRODY, S., SPARROW, C. D., AND KIBLER, H. H. 1926 Time relations of growth. II. The equivalence of age in mammals estimated on the basis of their growth constants. *Jour. Gen. Physiol.*, vol. 9, pp. 285–308.
- CASTLE, W. E. 1922 Size inheritance in rabbit crosses. *Carnegie Inst. Wash. Pub.* 320

- CASTLE, W. E. 1929 A further study of size inheritance in rabbits, with special reference to the existence of genes for size characters. *Jour. Exp. Zööl.*, vol. 53, pp. 421-454.
- CASTLE, W. E. (IN COLLABORATION WITH WALTER, MULLENIX, AND COBB) 1909 Studies of inheritance in rabbits. *Carnegie Inst. Wash. Pub.* 114.
- COLLINS, G. N. 1921 Dominance and vigor of first generation hybrids. *Am. Nat.*, vol. 55, pp. 116-133.
- CROZIER, W. J. 1926 On curves of growth, especially in relation to temperature. *Jour. Gen. Physiol.*, vol. 10, pp. 53-75.
- CUÉNOT, L. 1928 Génétique des souris. *Bibliographia Genetica*, vol. 4, pp. 179-242.
- DANFORTH, C. H. 1927 Hereditary adiposity in mice. *Jour. Hered.*, vol. 18, pp. 153-162.
- DAVENPORT, C. B. 1917 Inheritance of stature. *Genetics*, vol. 2, pp. 313-389.
- 1926 Human growth curve. *Jour. Gen. Physiol.*, vol. 10, pp. 205-216.
- DETLEFSEN, J. A. 1914 Genetic studies on a cavy species cross. *Carnegie Inst. Wash. Pub.* 205.
- DETLEFSEN, J. A., AND ROBERTS, E. 1918 On a back-cross in mice involving three allelomorphic pairs of characters. *Genetics*, vol. 3, pp. 573-598.
- DONALDSON, H. H. 1919 Quantitative studies on the growth of the skeleton of the albino rat. *Am. Jour. Anat.*, vol. 26, pp. 237-314.
- DUNN, L. C. 1928 The effect of inbreeding on the bones of the fowl. *Storrs Agr. Exp. Sta. Bull.*, vol. 152, pp. 55-112.
- EAST, E. M. 1916 Studies on size inheritance in *Nicotiana*. *Genetics*, vol. 1, pp. 164-176.
- EMERSON, E. A., AND EAST, E. M. 1913 The inheritance of quantitative characters in maize. *Exp. Sta. Neb. Res. Bull.*, vol. 2.
- FROST, H. B. 1923 Heterosis and dominance of size factors in *Raphanus*. *Genetics*, vol. 8, pp. 116-153.
- GATES, W. H. 1925 Litter size, birth weight, and early growth rate of mice (*Mus musculus*). *Anat. Rec.*, vol. 29, pp. 183-193.
- 1926 The Japanese waltzing mouse. *Carnegie Inst. Wash. Pub.* 337, pp. 83-138.
- 1927 Linkage of short ear and density in the house mouse. *Proc. Nat. Acad. Sci.*, vol. 13, pp. 575-578.
- GOLDSCHMIDT, R. 1913 Zuchtversuche mit Enten. I. *Zeitschr. f. ind. Abst. u. Vererb.*, Bd. 9, S. 161-191.
- HAMMETT, F. S. 1925 A comparison of bone growth in length with bone growth in weight. *Jour. Gen. Physiol.*, vol. 9, pp. 63-71.
- HOWELL, A. B. 1924 Individual and age variations in *Microtus montanus* yosemita. *Jour. Agr. Res.*, vol. 28, pp. 997-1016.
- JOHANNSEN, W. 1909 Elemente der exakten Erblchkeitslehre. Jena.
- KING, H. D. 1915 The growth and variability in the body weight of the albino rat. *Anat. Rec.*, vol. 9, pp. 751-776.
- 1923 The growth and variability in the body weight of the Norway rat (*Mus norvegicus*). *Anat. Rec.*, vol. 25, pp. 79-94.

- KING, H. D., AND DONALDSON, H. H. 1929 Life processes and size of the body and organs of the gray Norway rat during ten generations in captivity. *American Anatomical Memoir*, no. 14, pp. 3-106.
- KOPEĆ, S. 1927 Zur Kenntnis der Vererbung der Körperdimensionen und der Körperform beim Haushuhn. *Zeitschr. f. ind. Abst. u. Vererb.*, Bd. 45, S. 87-104.
- LATIMER, H. B. 1924 Postnatal growth of the body, systems and organs of the single-comb white Leghorn chicken. *Jour. Agr. Res.*, vol. 29, pp. 363-397.
- 1927 Postnatal growth of the chicken skeleton. *Am. Jour. Anat.*, vol. 40, pp. 1-57.
- LINDSTROM, S. W. 1926 Hereditary correlation of size and color characters in tomatoes. *Iowa Agri. Exp. Sta. Res. Bull.*, vol. 93, pp. 99-128.
- 1928 Linkage of size, shape, and color genes in *Lycopersicum*. *Verhandlungen des V. Internationalen Kongresses für Vererbungswissenschaft*. Berlin Supplementband II. *Zeitschr. f. ind. Abst. u. Vererb.*, S. 1031-1057.
- 1929 Linkage of qualitative and quantitative genes in maize. *Am. Nat.*, vol. 63, pp. 317-327.
- LITTLE, C. C. 1917 The relation of yellow coat color and black-eyed white spotting of mice in inheritance. *Genetics*, vol. 2, pp. 433-444.
- 1927 Preliminary report on a species cross in rodents. *Mus musculus* × *Mus wagneri*. *Papers of the Mich. Acad. Sci. Arts and Letters*, vol. 8, pp. 393-399.
- 1927 a Notes on a species cross in mice and on an hypothesis concerning the quantitative potentiality of genes. *Sci., N.S.*, vol. 66, pp. 542-543.
- LIVESAY, E. A. 1930 An experimental study of hybrid vigor or heterosis in rats. *Genetics*, vol. 15, pp. 17-54.
- LYNCH, C. J. 1921 Short ears, an autosomal mutation in the house mouse. *Amer. Nat.*, vol. 55, pp. 421-426.
- MACDOWELL, E. C. 1914 Size inheritance in rabbits. *Carnegie Inst. Wash. Pub.* 196.
- 1928 The growth curve of the suckling mouse. *Sci., N.S.*, vol. 68, p. 650.
- PARKES, A. S. 1926 The growth of young mice according to the size of litter. *Ann. Applied Biol.*, vol. 13, pp. 374-394.
- PEASE, M. S. 1928 Experiments on the inheritance of weight in rabbits. *Jour. Gen.*, vol. 20, pp. 261-309.
- PHILLIPS, J. C. 1912 Size inheritance in ducks. *Jour. Exp. Zoöl.*, vol. 12, pp. 369-380.
- 1914 A further study of size inheritance in ducks with observations on the sex ratio of hybrid birds. *Jour. Exp. Zoöl.*, vol. 16, pp. 131-145.
- PUNNETT, R. C., AND BAILEY, P. G. 1914 On the inheritance of weight in poultry. *Jour. Gen.*, vol. 4, pp. 23-29.
- 1918 Genetic studies on rabbits. I. On the inheritance of weight. *Jour. Gen.*, vol. 8, pp. 1-25.

- ROBERTSON, T. B. 1916 Experimental studies on growth. II. The normal growth of the white mouse. *Jour. Biol. Chem.*, vol. 24, pp. 363-383.
- 1923 The chemical basis of growth and senescence. *Monographs on Exp. Biology*. Philadelphia.
- 1926 The analysis of the growth of the normal white mouse into its constituent processes. *Jour. Gen. Physiol.*, vol. 8, pp. 463-507.
- SALLER, K. 1925 Biometrische Messungen an Laboratoriumsversuchstieren. I. Teil. Frosch und Maus. *W. Roux' Archiv. f. Entwicklungsmechanik*, Bd. 105, S. 732-777.
- SAX, K. 1923 The association of size differences with seed coat pattern and pigmentation in *Phaseolus vulgaris*. *Genetics*, vol. 8, pp. 552-560.
- 1924 The nature of size inheritance. *Proc. Nat. Acad. Sci.*, vol. 10, pp. 224-227.
- SCHMALHAUSEN, I. 1929 Zur Wachstumstheorie. *W. Roux' Archiv für Entwicklungsmechanik*, Bd. 116, S. 567-603.
- SCHNEIDER, M., AND DUNN, L. C. 1924 On the length and variability of the bones of the White Leghorn fowl. *Anat. Rec.*, vol. 27, pp. 229-239.
- SNELL, G. D. 1929 An inherent defect in the theory that growth rate is controlled by an autocatalytic process. *Proc. Nat. Acad. Sci.*, vol. 15, pp. 274-281.
- STIEVE, H. 1923 Untersuchungen über die Wechselbeziehungen zwischen Gesamtkörper und Keimdrüsen. II. Beobachtungen und Versuche an männlichen Hausmäusen und an männlichen Feldmäusen, zugleich ein weiterer Beitrag zur Zwischenzellenfrage. *Archiv f. mikr. Anat.*, Bd. 99, S. 390-570.
- SUMNER, F. B. 1923 Studies of sub-specific hybrids in *Peromyscus*. *Proc. Nat. Acad. Sci.*, vol. 9, pp. 47-52.
- 1923 a Results of experiments in hybridizing subspecies of *Peromyscus*. *Jour. Exp. Zool.*, vol. 38, pp. 245-292.
- 1927 Linear and colorimetric measurements of small mammals. *Jour. Mammalogy*, vol. 8, pp. 117-206.
- WARREN, D. C. 1927 Hybrid vigor in poultry. *Poultry Sci.*, vol. 7, pp. 1-8.
- WATSON, J. B. 1905 The effect of the bearing of young upon the body weight and the weight of the central nervous system of the female white rat. *Jour. Comp. Neur. and Psych.*, vol. 15, pp. 514-524.
- WRIGHT, S. 1922 The effects of inbreeding and crossbreeding on the guinea pigs. I. Decline in vigor. II. Differentiation among inbred families. *U. S. Dept. Agr. Bull.* 1090, pp. 1-63.
- 1922 a The effects of inbreeding and crossbreeding on guinea pigs. III. Crosses between highly inbred families. *U. S. Dept. Agr. Bull.* 1121, pp. 1-60.

